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Improvement of Diagnostic Flow Chart in Severe Accident Management Guidance for Nuclear Power Plants in Korea

So Won Jang [a*], Su Won Lee [a], Hae Cheol Oh [b]
[a]*FNC Technology Co., Ltd.,32 Fl., 13 Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, Korea*
[b]*Korea Hydro & Nuclear Power Co., Ltd. Central Research Institute,70 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: swjang@fnctech.com*

1. Introduction

A preliminary study for developing accident management plans for Nuclear Power Plants (NPPs) in Korea was conducted in July 1997 [1]. Based on this study, a research, "The Development of Accident Management Guidance for Korea Standard Nuclear Power Plants," was performed, and the generic Severe Accident Management Guidance (SAMG) for NPPs in Korea has been developed in November 1999 [2]. Structure of the Korean SAMG was adopted from Westinghouse Owner's Group (WOG) SAMG [3].

Development of generic SAMG in the United States was undertaken by WOG, Combustion Engineering Owner's Group (CEOG), and Babcock and Wilcox Owner's Group (BWOG) in the 1990s. They made efforts to develop generic SAMG specific to the individual plant designs to satisfy the regulatory concerns for severe accident managements.

Recently, the SAMG of the Pressurized Water Reactor Owner's Group (PWROG) [4] which is applicable to Babcock and Wilcox (B&W), Combustion Engineering (CE), and Westinghouse Pressurizer Water Reactor (PWR) Nuclear Steam Supply System (NSSS) designs was developed in February 2016 by incorporating the best features from the previous PWR generic SAMG. However, the structure of the PWROG SAMG is also based on the WOG SAMG.

The purpose of this study is to provide improvements of the Korean SAMG by comparing between the Korean SAMG and the PWROG SAMG to reflect the state of the art and trends.

2. Comparison between the Korean SAMG and the PWROG SAMG

2.1 The Similarities between the Korean SAMG and the PWROG SAMG

In WOG SAMG, the Diagnostic Flow Chart (DFC) and the Severe Challenge Status Tree (SCST) are separated while the DFC in the Korean SAMG integrates the conditions from the SCST, and performs the same function with a merged flow chart. The integrated DFC in the Korean SAMG has an advantage that a Technical Support Center (TSC) manager can comprehend the overall plant safety and severe challenge parameters to mitigate a severe accident at a glance. In the PWROG SAMG, the DFC and the SCST are also integrated with a Diagnostic Process Guideline (DPG), same as with the Korean SAMG.

Additionally, since the only difference between the structure of the Severe Accident Guideline (SAG) and the Severe Challenge Guideline (SCG) of the WOG SAMG is a step to identify and evaluate the negative impacts by implementing the strategies and the contents of two separate guidelines are very similar, the SAG and the SCG are combined in the Korean SAMG. An additional sub-step to identify whether a severe challenge parameter exceeds a setpoint is included in the SAGs. And, the SAGs and SCGs also are merged with TSC SAGs (SAG-3 through SAG-10) in the PWROG SAMG.

Even though the Korean SAMG and the PWROG SAMG were developed based on the WOG SAMG by different SAMG developers, the overall structure of the Korean SAMG and the PWROG SAMG is similar as described above. It means that the philosophy for the development of the Korean SAMG and the PWROG SAMG is identical.

2.2 The Differences between the Korean SAMG and the PWROG SAMG

The PWROG SAMG consists of four major parts, Main Control Room (MCR) SAGs (SAG-1 and SAG-2), DPG, TSC SAGs (SAG-3 through SAG-10), and Technical Support Guidelines (TSGs). The MCR SAGs, the DPG and the TSC SAGs in the PWROG SAMG have similar functions of the Severe Accident Control Room Guidelines (SACRGs), the DFC, and the SAGs in the Korean SAMG respectively. One of the TSGs (TSG-5) in the PWROG SAMG contains the Computational Aids (CAs), and these CAs are almost identical with the CAs in the Korean SAMG.

However, the details of the PWROG SAMG are different with the Korean SAMG. Especially, the DPG in the PWROG SAMG replaces the tools adopted in the WOG SAMG as well as the Korean SAMG. The DFC in the Koran SAMG is a flow chart as shown in Fig. 1. On the other hands, the DPG consists of a parameter worksheet that provides a visual hierarchy of plant conditions and a color coded scheme that identifies the severity of the conditions. In this section, the differences between the DFC in the Korean SAMG and the DPG in the PWROG SAMG are identified in the view point of the improvements of the Korean SAMG.

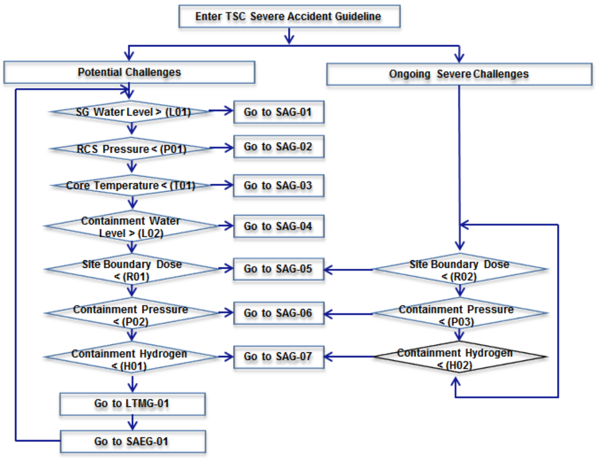

Fig. 1. The current DFC in the Korean SAMG

2.2.1 The Level to Identify the Severity of the Plant Conditions

The DFC of the Korean SAMG consists of two levels to identify the severity of the plant conditions: potential challenges and ongoing severe challenges to fission products boundaries as illustrated in Fig. 1. The ongoing severe challenges have higher priority than the potential challenges in the DFC.

On the other hand, the parameter worksheet of the DPG in the PWROG SAMG has four levels: "Red", "Orange", "Yellow", and "Green". It is arranged with the most severe color at the left. The "Red" conditions on the parameter worksheet indicate an ongoing severe challenge. The "Green" conditions to the right signify desirable plant conditions or target conditions which, when satisfied, do not require any corrective action. If there are no "Red" conditions, any "Orange" condition should be addressed first. If no "Orange" conditions exist, then any "Yellow" condition should be addressed. In other words, "color" of the conditions signifies the first order of priority in the DPG.

As described above, the concept of the DFC and the DPG is similar, but the DPG has more detail levels to identify the severity of the plant conditions for implementing the strategies in accordance with the SAGs.

2.2.2 The Order of Priority of the Strategies

The Korean SAMG has seven major strategies to mitigate severe accident as follows:

SAG-01: Injection into the Steam Generator
SAG-02: Depressurize the RCS
SAG-03: Injection into the RCS
SAG-04: Injection into the Containment
SAG-05: Control Fission Product Release
SAG-06: Control Containment Conditions
SAG-07: Control Containment Hydrogen

And, the implementation order of these strategies of the Korean SAMG in terms of priority is in the same order as above. In the case of the PWROG SAMG, the order of priority from the SAG-01 to the SAG-04 is the same with the Korean SAMG. However, the order of priority of the other SAGs in the PWROG SAMG is different as follows:

TSC SAG-7: Reduce Containment Hydrogen
TSC SAG-8: Control Containment Pressure
TSC SAG-9: Mitigate Fission Product Release

In the PWROG SAMG, because the containment hydrogen condition can limit the ability to perform actions to depressurize containment, the hydrogen reduction has a higher priority than the containment pressure control. And, the actions regarding the fission product release mitigation are important to overall reduction and mitigation of the releases, but those would tend to be less direct than the action in the other strategies. Thus, TSC SAG-9 has the lowest order of priority.

2.2.3 The Entry Parameter into the Strategy

The entry parameter into each major strategy is the same between the Korean SAMG and the PWROG SAMG excluding the entry parameter into the SAG-03. In Korean SAMG, the parameter to enter SAG-03 is the core temperature. However, RCS injection flow rate is used as the entry parameter in the PWROG SAMG since the core temperature indication may be not reliable as an accurate indication of core cooling in a severe accident. The RCS injection flow rate is reliable because it is probable that injection into the vessel will reach the core regardless of the location of the core (in-vessel or ex-vessel).

2.2.4 The Integration of Guidelines

The purpose of LTMG-01 (TSC Long Term Monitoring) is to provide information for TSC to monitor the long term concerns associated with strategy implementation. And purpose of the SAEG-01 (SAMG Termination) is to provide information for the TSC that is important to supplement recovery actions after the use of SAMG is discontinued. DFC, LTMG-01, and SAEG-01 are separated as another guideline in Korean SAMG. Meanwhile DFC, LTMG-01, and SAEG-01 are integrated as the DPG in PWROG SAMG which performs the same function as the guidelines in Korean SAMG. DPG contains the steps that are monitoring the long term concerns and implementing recovery actions in the LTMG-01, and are checking exit parameters and assessing plant state in SAEG-01. TSC can make a decision to perform strategy more rapidly without conversion of guidelines.

2.2.5 The Occurrence of Core Concrete Interaction (CCI)

In the DFC of the Korean SAMG, to identify whether CCI has occurred or not, TSC checks correlation between the containment pressure and temperature using the Fig. 2 on DFC, which illustrates the superheat and CCI, and saturated steam-air mixture curve, respectively. If current plant states correspond to superheat and CCI curve, then CCI assumed to have occurred. However, TSC has no explicit direction when the containment pressure and temperature are out of range described in the curve.

Whereas in DPG of PWROG SAMG, TSC checks the pressure difference between RCS and containment, and the containment water level for the first step to determine if CCI has occurred. And if CCI has occurred, TSC identifies the time after reactor vessel failure for the next step. TSC can make a decision when TSC conducts hydrogen control strategies by using the elapsed time of CCI in CA-3 (Hydrogen Flammability in Containment) of PWROG SAMG, given the predicted generated amount of CO following the CCI.

If CCI has occurred, the production of CO following the CCI is a significant contributor to the amount of flammable gases presented in containment as a hazard source for hydrogen combustion. And the effects of CCI on the flammable gases presented in the containment depend on the time elapsed since CCI began. To minimize uncertainties of production of the flammable gases according to duration time of CCI, Figures for 2, 8, and 16 hours corresponding to the elapsed time of CCI are presented in CA-3 of PWROG SAMG.

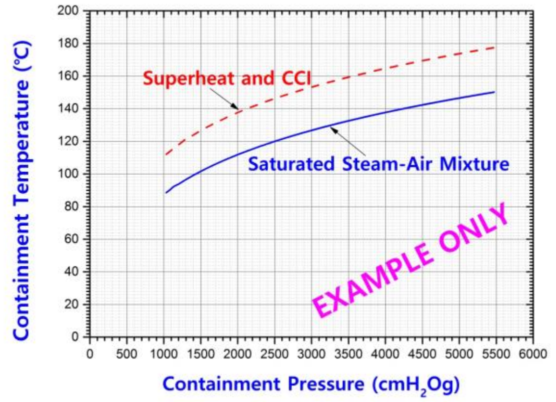

Fig. 2. Potential correlation between the containment pressure and temperature

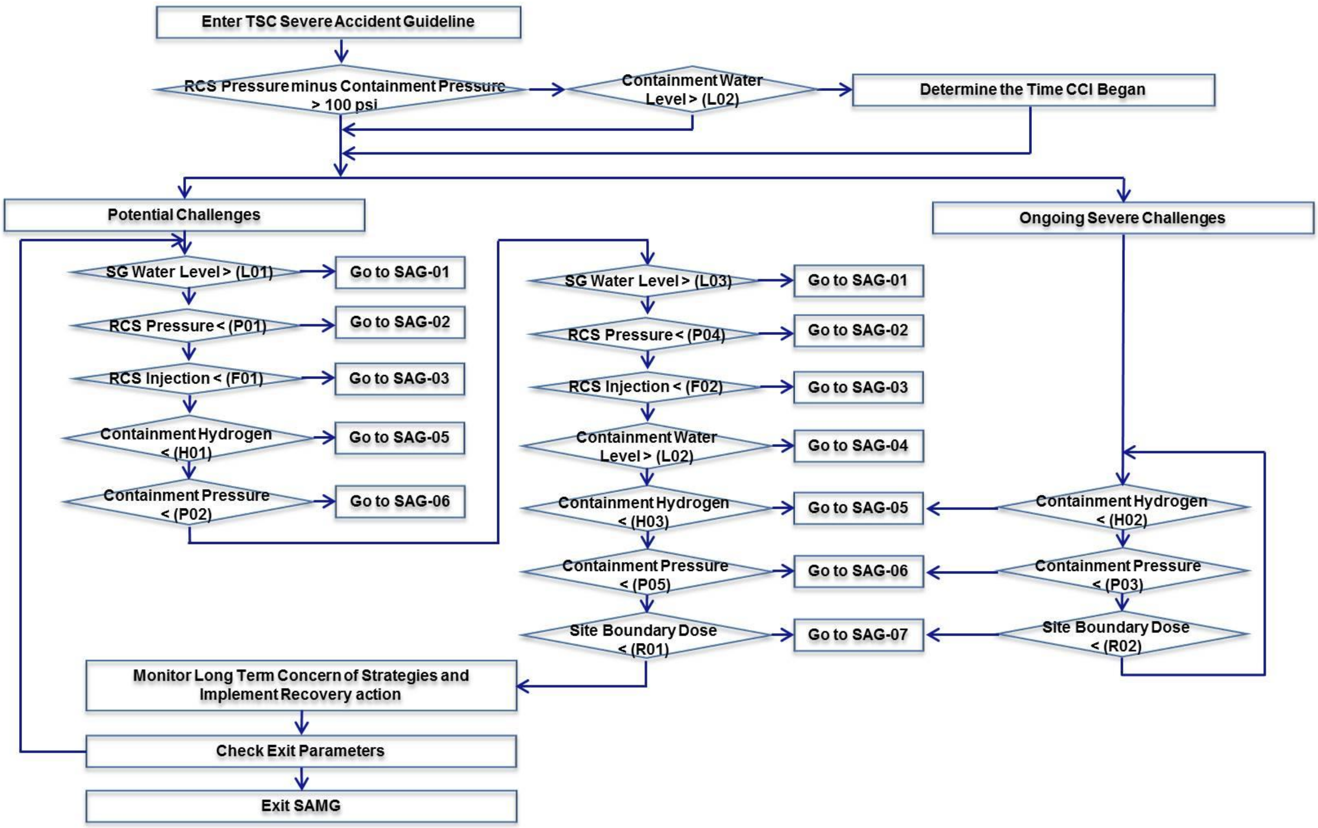

Fig. 3. The improved DFC in the Korean SAMG

3. Improvements of the Korean SAMG

As described in Section 2.2, the DFC in the Korean SAMG and the DPG in the PWROG SAMG have five major differences. And, it is considered that the DPG in the PWROG SAMG has more effective capabilities compared to the DFC in the Korean SAMG in the view points of the level to identify the severity of the plant conditions, the order of priority of the strategies, and the suitability of the entry parameter. Thus, it is better to adopt the concepts of the DPG in the PWROG SAMG for the Korean SAMG.

Figure 3 shows an improved DFC to reflect the concepts of the DPG. The flow chart form of the DFC in the Korean SAMG is maintained, but the level to identify the severity of the plant conditions can be diversified with various setpoints as illustrated in Fig. 3. All setpoints used in the improved DFC have already been defined in the Korean SAMG. Thus, it is not necessary to define new setpoints to apply the improved DFC. And, the order of priority for the SAG-05, SAG-06, and SAG-07 is changed, the entry condition into the SAG-03 is modified from the core temperature to the RCS injection flow rate, and LTMG-01and SAEG-01 come under the DFC as parts of the steps. Furthermore the step identifying the occurrence of CCI is added in the DFC. Additionally Fig. 4, 5 and 6 are the examples of potential for hydrogen combustion containment as 2, 8, and 16hours corresponding to the elapsed time of CCI, respectively.

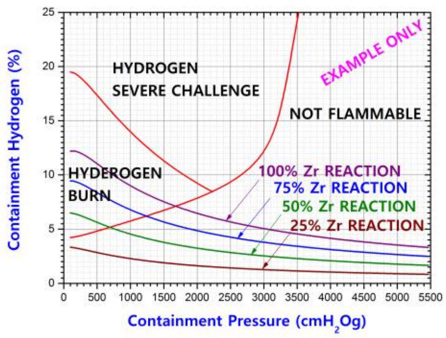

Fig. 4. Potential for Hydrogen Combustion Based on Wet Hydrogen Measurement (2 hours of CCI)

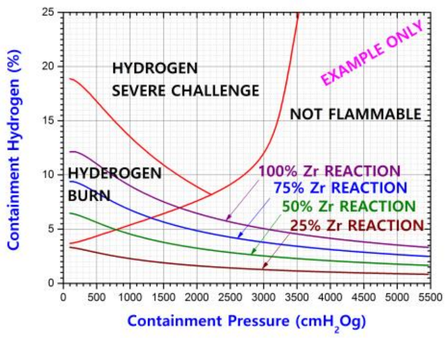

Fig. 5. Potential for Hydrogen Combustion Based on Wet Hydrogen Measurement (8 hours of CCI)

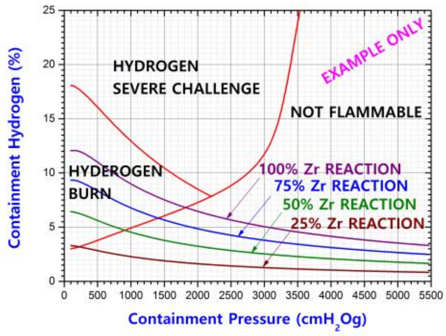

Fig. 6. Potential for Hydrogen Combustion Based on Wet Hydrogen Measurement (16 hours of CCI)

4. Conclusions

The improved DFC for the Korean SAMG is proposed by comparing between the Korean SAMG and the PWROG SAMG. If the improved DFC is adopted, the level to identify the severity of the plant condition is diversified, the order of priority of the strategies is changed, the entry condition into the RCS injection strategy is changed, LTMG-01and SAEG-01 come under the DFC as parts of the step, and the step whether CCI is occurred or not is added in DFC. In order to increase the effectiveness of the Korean SAMG and to reflect the state of the art and trends, it is appropriate to apply the suggestions contained in this paper to the Korean SAMG.

REFERENCES

[1] TR.96NJ11.97.77, "Preliminary Study for Development of Accident Management Plans in NPPS," Korea Atomic Energy Research Institute, September 1997.

[2] KAERI/RR-1939/98, "Development of Accident Management Guidance for Korean Standard Nuclear Power Plant," Korea Atomic Energy Research Institute, November 1999.

[3] "Westinghouse Owners Group Severe Accident Management Guidance," Westinghouse Electric Co., Revision 0, June 1994.

[4] PWROG-15015-P, "PWROG Severe Accident Management Guidelines," Westinghouse Electric Co., Revision 0, February 2016.